Mid and High Frequency Ocean Acoustic Channel Variability and Its Impact on Underwater Acoustic Communications

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LONG-TERM GOALS

Extensive research on the impact of channel variability on mid and high frequency acoustic communications systems has highlighted the important role that surface scattered signals play in determining the performance achievable by these systems. The surface scattered paths show the greatest amount of high dimensional variability (as opposed to the well structured and low degrees of freedom variability caused by platform motion) of the different propagation paths and pose significant challenges to reliable system operation. The long term goals of this work are to develop physics based deterministic and statistical models for this channel variability to exploit in the development of improved algorithm for optimizing communications system structure (topology, protocols, etc.) as well as the transmission of and processing.

OBJECTIVES

The long term scientific objectives of the proposed work are to

1. establish an understanding of the deterministic surface wave focusing phenomena and its dependence on geometry (orientation of the propagation path with respect to the surface wave field, range, and depth) as well as the characteristics of the surface wave field,

2. develop methods of characterizing communications channel quality and its evolution with range and dependence on surface scattering, and

3. develop representations of the underwater acoustic communications channel and its fluctuations that can be exploited by signal processing and communications algorithms, and

APPROACH

The approach to pursuing these objectives includes 3 parallel efforts. The first is to apply deterministic acoustic models to develop expressions that link physical parameters to acoustic parameters of interest such as scattered signal intensity. The second is to use data from controlled tank experiments to validate the derived expressions and develop insights into the extension of the deterministic expressions to statistical characterizations. The third is to analyze field data to both check the applicability of the derived expressions but also develop insights that guide the development of the

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14. ABSTRACT
Extensive research on the impact of channel variability on mid and high frequency acoustic communications systems has highlighted the important role that surface scattered signals play in determining the performance achievable by these systems. The surface scattered paths show the greatest amount of high dimensional variability (as opposed to the well structured and low degrees of freedom variability caused by platform motion) of the different propagation paths and pose significant challenges to reliable system operation. The long term goals of this work are to develop physics based deterministic and statistical models for this channel variability to exploit in the development of improved algorithm for optimizing communications system structure (topology, protocols, etc.) as well as the transmission of and processing.

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desired expressions. The field data will also be used to quantify statistical measures of channel variability as part of the effort to develop meaningful low rank representations of channel variability.

WORK COMPLETED

The major effort (from a time point of view) this year was the execution and subsequent demobilization from the SPACE08 experiment. Work has also involved continuing to serve the data needs of the numerous PIs who relied on the experiment for field data. This has involved quality checking data as well as analysis of environmental records to identify "interesting" time periods for further environmental and acoustic modeling and analysis.

We have analyzed field data from the SPACE02 experiment focusing on quantifying the fading statistics (the intensity fluctuations of a single surface scattered arrival) of the single surface bounce paths (surface, bottom-surface, surface-bottom, and bottom-surface-bottom). We have looked at the form of the fading pdfs as a function of weather condition (significant wave height and wind speed), range, and signal bandwidth.

We have developed deterministic analytic expressions for the intensity and Doppler shifts of surface scattered signals as a function of wave shape and wave speed.

We have analyzed data from the Wavefronts Tank experiment to validate analytic expressions for the intensity of a surface scattered signal.

We have worked on the analysis of data from the Wavefronts V experiment for further analysis of surface scattering physics in realistic wave fields.

We have analyzed data from the SPACE08 experiment to develop an understanding of the dependence of range and Doppler spreading of the channel impulse response as a function of source to receiver range and weather conditions. This work is on-going.

RESULTS

We now have analytical expressions relating surface wave characteristics and source receiver geometry to the intensity and Doppler shift of a surface scattered arrival. The interesting result is that the dependence of intensity on surface wave characteristic relies on only the slope and the second derivative of surface elevation with range while the Doppler depends on wave speed in addition to these two parameters. A Fourier expansion of these two parameters of the surface wave field shows a order k and order k-squared (k is the wavenumber) dependence, respectively, for slope and the second derivative. This implies a sensitivity that increases with wavenumber. These relations will provide the basis for the development of subsequent statistical models.

The analysis of SPACE02 data has shown that under a wide range of surface conditions, the intensity fluctuations of the surface scattered signals are well modeled by heavy tailed pdfs. Two pdfs that provide good matches for different measures of intensity are the K-distribution and the log-normal distribution. These conclusions are surprisingly robust under different surface wave conditions. As the bandwidth of the signals is decreased or the range increases (out to 1000 meters for example in the 15 meter water depths of the SPACE02 experiment) the intensity statistics approach the expected and widely used Rayleigh pdf.

We have developed a simple inverse filter that can be used to process measurements of the surface wave field that are taken with pressure sensors to "recover" come of the high wavenumber components of the surface wave field that are lost due to the attenuation of this signal with depth. This has allowed us to extend the usefulness of the surface wave measurements that we do have.

IMPACT/APPLICATIONS

The work described herein is directly applicable to the improvement of signal processing algorithms and network topology optimization for underwater acoustic communications. We are in the process of demonstrating this for the improvement of channel estimation algorithms by using the fading statistics to "regularize" the channel estimation problem using a Maximum A Posteriori estimator when we are using very short averaging windows to accommodate rapid channel fluctuations.

RELATED PROJECTS

ONR Ocean Acoustics funded MURI on underwater acoustic communications titles "Underwater Acoustic Propagation and Communications: A Coupled Research Program".

ONR Undersea Signal Processing funded grant titled "Joint Development of Forward Error Correction, Channel and Data Estimation Algorithms for Reliable Underwater Acoustic Communications".

PUBLICATIONS

M. Stojanovic, J. Preisig, "Underwatrer Acoustic Communications Channels: Propagation Models and Statistical Characterization", [Published, IEEE Trans. On Communications, Special Issue on Underwater Wireless Communications, refereed]

C. Tindle, G. Deane, J. Preisig, "Reflection of underwater sound by surface waves", [Published, JASA, refereed]